

**The Interpretation of Quantum Mechanics.** By Roland Omnès. Princeton University Press, Princeton, New Jersey, 1994, xiv + 550 pp., \$95.00 (hardback), \$39.50 (paperback).

This monograph is the first book-length treatment of the consistent histories approach to the interpretation of quantum mechanics which I initiated in 1984, and to which Omnès (starting in 1987) and Gell-Mann and Hartle (starting in 1990) have made major contributions. While consistent historians do not agree on every detail, there is a common core of ideas which can be summarized as follows. A closed quantum system (the universe, if one is ambitious) is represented by a Hilbert space, and anything that can sensibly be said about it at a particular time is represented by some subspace of this Hilbert space; in other words, there are no hidden variables. A *history* consists of a sequence of subspaces  $E_1, E_2, \dots$  associated with times  $t_1, t_2, \dots$ , understood as events occurring, or properties which are true, at these times. Provided the history is a member of a *consistent family* of histories, it can be assigned a probability, and within a given consistent family these probabilities function in the same way as those of a classical stochastic theory (imagine a sequence of coin tosses): one and only one of them occurs, and the theory assigns a probability to each possibility. Inconsistent histories, those which do not belong to a consistent family, are meaningless. The unitary time evolution generated by the Schrödinger equation, without any stochastic or nonlinear modifications, is used both for determining the *consistency conditions* which define consistent families, and for calculating the probabilities of histories belonging to a particular family.

Measurements play no fundamental role in the consistent history interpretation; they simply correspond to sequences of events inside a closed system in which the measurement apparatus, along with everything else, is treated quantum mechanically. Thus a possible history for a closed system in which there is an apparatus for measuring the  $z$  component of the spin of a particle might include an initial state, a value of  $S_z$  at a time shortly before the particle reaches the apparatus, and the position of a pointer on the apparatus at some later time. Using conditional probabilities one can show, under suitable conditions, that the particle earlier had the property indicated later by the pointer position. In this and various other ways the consistent history approach replaces the smoky dragons which inhabit textbook and other treatments of “measurement” with precise mathematical and logical rules yielding results which are often much closer to the intuition of experimental physicists than to what one finds in the literature on quantum foundations.

The first two chapters of the book contain an introduction to quantum mechanics and the Copenhagen interpretation, thus setting the stage for the material which follows. Chapters 3 and 4 give a number of basic tools of the consistent history approach, including definitions of properties, histories, and the consistency conditions. Omnès’ consistency

condition resembles my original proposal[1], and he makes no use of the alternatives suggested by Gell-Mann and Hartle[2], one of which I myself now prefer. His generalization of my definition of a (possibly consistent) family of histories is probably a step in the right direction, but its physical significance is hard to judge, since (despite assertions to the contrary on pp. 136, 189, and footnote 19 of p. 462) all of the examples in the book seem to fit my original proposal.

Chapter 5 is devoted to the logical framework of the theory, an area in which Omnès has made a major contribution. The essential idea can be illustrated in classical terms by imagining tossing a coin three times in succession. The result will be one of a set  $S$  of 8 possible histories, or sequences of heads and tails, and a proposition such as “heads occurred once on the first two tosses” corresponds to a subset of  $S$ , those histories for which it is true. Negation of a proposition and the conjunction of two propositions then correspond to operations on subsets, and logical implication to one subset falling inside another. In the quantum case one uses the same approach, with  $S$  the set of elementary histories in a *single* consistent family. Omnès actually sets up the idea of implication using conditional probabilities rather than set theoretic inclusion, which does not change the main idea. (Unfortunately his system as stated does not satisfy the rules of App. A to Ch. 5, though this can probably be remedied fairly simply.) Omnès refers to the propositions, etc. of a single consistent family as a “logic”. What distinguishes the quantum from the classical world is that in the former there are many “logics” (consistent families) which can, at least potentially, refer to the same physical system, but which are mutually incompatible in the sense that if history  $H$  belongs to “logic”  $L$  and history  $H'$  to “logic”  $L'$ , there may be no “logic” which contains both  $H$  and  $H'$ . Sound quantum reasoning must conform to Omnès’ Rule 4 (p. 163): *Any description of the properties of an isolated physical system must consist of propositions belonging together to a common consistent logic. Any reasoning to be drawn from the consideration of these properties should be the result of a valid implication or of a chain of implications in this common logic.*

I agree with Omnès that one must have a rule of this form, and I think he has expressed it quite well. But I think still more is needed in order to specify what constitutes sound reasoning in the quantum domain. In particular, Rule 4 does not tell us *how* to choose the single “logic” (consistent family) to use for a reasoning process. While this choice is sometimes obvious, in other cases it is not, especially since a single history can belong to a number of mutually incompatible “logics”. This problem deserves a more careful discussion than it receives in this book or elsewhere in the consistent histories literature. It should be noted that the logic of the consistent history approach is significantly different from that proposed by Birkhoff and von Neumann[3].

Omnès’ formulation differs from my original proposal in the presence of a density matrix in the consistency condition and probability formulas, coupled with an interpreta-

tion which is not symmetrical under changing the direction of time. My current ideas[4] escape, I believe, the criticisms in App. D of Ch. 5 while still maintaining a structure invariant when reversing time, and without a density matrix. I think this shows that Omnès' time-asymmetric version is not a logical necessity, but instead reflects his use of a time-asymmetric set of axioms. I should add that, despite certain differences, there is a great deal of overlap between Omnès' ideas and mine, and their application to various gedanken experiments often leads to identical consequences.

Consistent historians all believe that the "classical world" of everyday experience can be understood in quantum mechanical terms by using the consistent history approach, but differ on the details of how to work out the correspondence. Gell-Mann and Hartle [2] suggest finding a consistent family or families in which classical laws represent an asymptotic approximation to fully quantum behavior. Omnès' approach, in Ch. 6, is to argue that a quantum description using quasi projectors corresponding to a cell in classical phase space can, under suitable conditions, be shown to yield, within errors which can be estimated, the same time development as the corresponding classical equations of motion. As I am not familiar with the mathematical tools he employs, I cannot comment on the technical aspects of the argument. Assuming it is correct, it seems to me it is not complete, for the correspondence holds only for a limited period of time, and in the case of a system which shows classical chaos, this time can be quite short. Omnès is not clear about what happens for longer times. He would probably agree with Gell-Mann and Hartle that some sort of stochastic behavior represents an appropriate quantum correction to classical laws. I find the conceptual foundation of the Gell-Mann and Hartle program a bit clearer, but they, too, have not worked out all the details. Both approaches would be impossible without the freedom, present in the consistent history framework, to talk about events occurring at successive times, rather than just measurements.

Chapter 7 considers decoherence, the effect upon a quantum system of its environment. Decoherence is an important physical phenomenon, and Omnès' discussion has much of value. I cannot, however, agree with his claim that decoherence somehow resolves the problem of macroscopic quantum superposition (MQS) states which besets traditional approaches to a quantum theory of measurements. Omnès is aware of Bell's criticism that arguments of the "for all practical purposes" type do not resolve fundamental questions, and he responds that the sort of measurements which could be used to detect the coherence in MQS states are "in principle" impossible, because, for example, they would require apparatus of physical size larger than the visible universe. However, it seems to me that the real import of Bell's critique is that if we understood quantum theory properly, there would be no need to extricate ourselves from conceptual difficulties by appealing to facts about the world which are not (or not obviously) part of quantum theory itself, so I do not find Omnès' solution satisfactory. But in addition there is an alternative approach

within the consistent history scheme itself which, it seems to me, adequately meets Bell's criticism: one uses a consistent family containing the outcomes of the measuring process ("pointer positions"), and if one employs this family or "logic", all references to the MQS states are excluded by Omnès' Rule 4: adding them to the discussion would render the family inconsistent. Perhaps Omnès does not agree with this central result of [1]; it seems not to occur in his discussions of decoherence and measurement.

Chapter 8, on the theory of measurement, begins with a derivation of a fundamental results of the consistent history approach: from the outcome of a measurement (e.g., the position of a pointer) one can, under suitable conditions, infer a property of the measured system (e.g., some component of the spin) at an earlier time. In other words, quantum measurements (when properly carried out) actually do what they are supposed to do. Next comes a discussion of "actual facts", the problem of why in the world around us we observe only one of the possible situations allowed by quantum theory. My own point of view[1] is that quantum theory is irreducibly stochastic, and thus the occurrence of a particular history is no more (or less) mysterious than the fact that if a coin is tossed three times in succession, only one of the eight possible results will actually occur. Omnès evidently does not accept this point of view. I think he should nonetheless have mentioned it among the options he lists on p. 493, as it is probably common among working physicists. The third topic in Ch. 8 is Omnès' concepts of "true" and "reliable". There are some serious flaws here, as pointed out by Dowker and Kent[5]. Omnès[6] believes they can be corrected, but in the meantime, their existence puts some of his conclusions in doubt. My own belief is that a more satisfactory approach would be to associate a separate notion of "true" with each "logic", but this idea[7] has not yet been spelled out in detail.

The discussion of the EPR paradox in Ch. 9 makes use of the "true" vs. "reliable" distinction just mentioned, and has other problems as well. What Omnès calls the "original EPR experiment" is not what one finds in the original EPR paper, though the paradoxical aspects are closely related. More serious, in my opinion, is that Omnès makes what one can say about a particular system dependent on the time at which a measurement is carried out on a distant system. This rather unnatural effect occurs in standard quantum treatments through the "collapse of the wave function" (something both Omnès and I reject, at least as a physical phenomenon), and I showed in 1987[8] that it is absent from a consistent history analysis. Perhaps this is one of the points at which Omnès' use of a time-asymmetric formulation makes some difference.

Chapters 10 and 11 of the book contain various applications to physical systems. In some instances, as in the decay of unstable particles, Omnès' treatment contains valuable insights. In others, as in his discussion of Josephson junctions, it is not clear to me that the discussion adds much to what is already in the literature on the subject. Chapter 12 is in two parts: the first is a summary of material in earlier chapters, and the second treats

various philosophical issues.

Generally speaking, the book is not easy to read. The style tends to be detailed and ponderous, and the overall direction of a particular argument is often not clear. Introductory passages where one might have hoped to find an overview preceding a detailed discussion tend not to be very helpful, for they contain a large number of peripheral comments and references to other sections, and occasionally the grammatical construction leaves the meaning of a sentence unclear. Sometimes material on a particular topic is divided into two parts placed in separate chapters for no apparent reason. The index is helpful but incomplete. I am afraid it will not be easy for readers unfamiliar with the consistent history approach to learn it from this book. On the other hand, it contains an enormous amount of relevant material, and thus can serve as a useful reference.

While it does have defects, I nevertheless admire this book as a bold attempt to give substance to a vision common to consistent historians, namely that our current scientific understanding of the physical world, macroscopic phenomena as well as microscopic, can be linked to a firm foundation of quantum mechanical principles by appropriate and precise rules of sound reasoning. There is no need to add hidden variables to the Hilbert space, or tinker with the Schrödinger equation, or restrict ourselves to talk about “measurements” in order to construct a coherent interpretation of quantum mechanics which overcomes the well-known conceptual problems which have given such trouble to those who have been attempting to understand the subject for the past seventy years. We are indebted to Omnès for showing how much of this program can actually be carried out within the consistent histories framework. Some imperfections are inevitable in a pioneering effort, and those portions of the book which I find problematical are nonetheless useful as indications of what needs to be better understood, or more clearly explained, or perhaps both.

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